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Extended Atmospheres of Outer Planet Satellites
and Comets

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16. Abstract

The lifetimes of hydrogen atoms in the environment of Saturn's magnetosphere can be expected to be quite long ($\sim 10^8$ s). Preliminary testing of our model of the Titan hydrogen torus for these long-lived orbits has begun. A draft of the paper describing the analysis of Pioneer Venus observations of Comet P/Encke has been completed and is included herein. Plans to analyze Comet P/Halley data, as well as the development of models for cometary carbon and oxygen, are also discussed.

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I. Program of Research for the Second Quarter

Research activites during the second quarter have concentrated primarily on (1) completion of a preliminary draft of a paper on the PVOUS Comet P/Encke hydrogen observations with A.I.F. Stewart, (2) broadening our collaborative effort with A.I.F. Stewart to include future analysis of Comet P/Halley observations, (3) initiation of cometary models for carbon and oxygen, and (4) preliminary testing of our Titan hydrogen torus model for modeling the Lyman-α data acquired by the Voyager 1 UVS instrument.
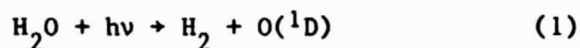
1. Cometary Atmospheres

During this past quarter, A.I.F. Stewart, of the Laboratory for Atmospheric and Space Physics at the University of Colorado, visited AER, Inc. During his visit we prepared a preliminary draft of a paper dealing with our analysis of the Pioneer Venus Orbiter UV observations of the extended hydrogen Lyman-α cloud of Comet P/Encke. A copy of the draft is included as part of this report. We were quite pleased with both the facility and economy of using the particle-trajectory model (PTM) for analyzing such data. The earlier results, discussed in the interim report for the first quarter of this project, represented essentially all the scientific analysis which was performed using low statistics model runs. One of the advantages of the PTM is the ability to run with as few or as many particles as necessary. For example, the model result shown in the previous quarterly report included 40,000 total H atoms the sky plane grid and used only 8 minutes CPU time on a VAX 11/780 class machine. This is typical of the type of low statistics model needed for day-to-day scientific analyses. The model shown with the data in Figure 3 of the attached paper contains 10 times as many particles for much better statistics and a smoother modeled scan, but was run with the same physical parameters as determined from the low statistics model.

During our meeting with Dr. Stewart, we also discussed an extension of our collaborative effort to include the analysis of PVOUVS Comet P/Halley observations which will begin early in 1986 shortly before perihelion. At that time, observations from near earth satellites will be virtually impossible because of the Earth-Sun-comet geometry, but Venus will be well placed. The PVOUVS data will include hydrogen, carbon, and oxygen (the three most abundant species), which are the subjects of study under this contract.

Thus, the combination of our two programs is natural and should potentially prove to be quite fruitful.

An examination of the photochemistry of H_2O, CO and CO_2 was begun this past quarter. These are the most probable candidates for the sources of the bulk of the cometary carbon and oxygen. The H_2O source for oxygen is found in two main reactions:

$$H_2O + h\nu \rightarrow H_2 + O(^1D) \qquad (1)$$

$$OH + h\nu \rightarrow H + O . \qquad (2)$$

The oxygen atoms produced by reaction (1) will be ejected from the center-of-mass of the H_2O molecule with a velocity of ~1.6 km/s. We have calculated this from the excess energy after photodissociation of 1.9 eV (Huebner and Carpenter 1979). The atoms formed in reaction (2) will be ejected from the moving OH radicals with a velocity of ~0.5 km/s. The sources of observed C and the remainder of observed O should be found in the photodissociation of CO and/or CO_2. There is some controversy as to whether CO or CO_2 is the more dominant parent molecule actually present in the icy cometary nuclei. By carefully modeling the kinematics and spatial distributions of C and O atoms and comparing these models to observations, we should be able to reasonably address this question.

2. Titan Hydrogen Torus

The overall objective of our research in the Saturn system is to understand the sources, sinks and also impact on the planetary magnetosphere of the hydrogen that is distributed throughout the circumplanetary space. The strategy adopted is to investigate the importance of Titan, the most likely dominant source of H, by comparison of hydrogen torus model calculations with observations of the Lyman-α emission data acquired by the Voyager 1 UVS instrument. This comparison will allow possible non-Titan sources to be identified.

The pre-Voyager Titan hydrogen torus model (Smyth, 1981) was improved last year to include the spatial lifetime of H atoms in the Saturn magneto-sphere. Loss processes for atomic hydrogen in the Saturnian system are summarized in Table 1. The lifetime of hydrogen in Saturn's equatorial plane,

3

based upon these loss processes and plasma data for the Saturn magnetosphere determined from Voyager encounter data by Sittler (1984) as part of a supporting collaborative effort, is given in Figure 1. For radial distances from Saturn larger than about 15 R_S, the lifetime produced by the planetary magnetosphere is about 1×10^8 sec and is comparable to the lifetime of hydrogen in the solar wind produced by charge exchange with protons. Inside of 15 R_S, the lifetime drops to values as low as $4-5 \times 10^6$ sec near 7 R_S. Photoionization lifetime of hydrogen at Saturn's distance from the Sun is near 1×10^9 sec as indicated in Figure 1. The lifetime of hydrogen produced by the magnetospheric plasma becomes larger as one departs from the equatorial plane as illustrated in Figure 2, with values eventually becoming comparable to the photoionization lifetime.

The lifetime of hydrogen atoms in the Saturn system therefore ranges from values as short as 1.5 months inside of Titan's orbit to values of order 3 to 30 years throughout much of the magnetosphere. Some testing of the Titan hydrogen torus model has been performed this quarter to determine the best procedure for including these very long lifetime hydrogen atoms accurately but at the same time economically. Additional effort has been expended in evaluating the recapture of hydrogen atoms by Titan and also in discussing with D.E. Shemansky the procedure for reformatting the Lyman-α emission data acquired by the Voyager 1 UVS instrument to be in use in this modeling effort.

II. Program of Research for the Third Quarter

Research activities during the third quarter in the area of comets will concentrate on the development of our models for carbon and oxygen. In addition, the writing of a paper documenting our AER particle-trajectory model will be initiated.

Research activities in the Saturn system will involve further testing of the Titan hydrogen torus model. A trip to visit Donald Shemansky in Tucson will be scheduled early in the third quarter to facilitate the formatting of the Lyman-α data for the Titan H torus acquired by the Voyager 1 UVS instrument.
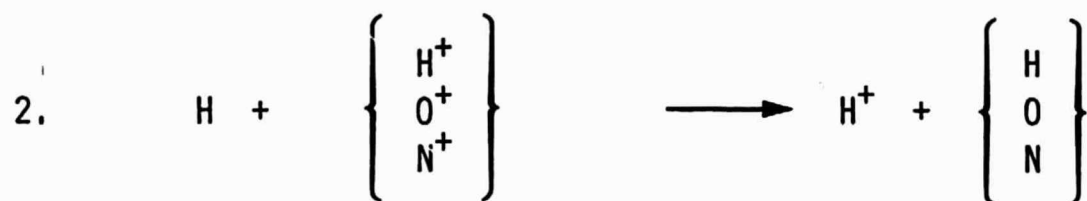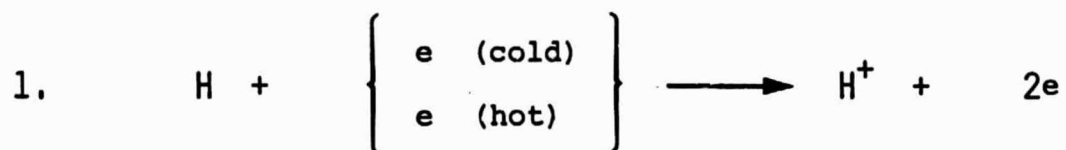
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Table 1

LOSS PROCESSES FOR ATOMIC HYDROGEN IN THE SATURNIAN SYSTEM

1. $\quad$ H $+$ $\left\{ \begin{array}{l} e \quad \text{(cold)} \\ e \quad \text{(hot)} \end{array} \right\}$ $\longrightarrow$ $H^+ +$ $2e$

2. $\quad$ H $+$ $\left\{ \begin{array}{l} H^+ \\ O^+ \\ N^+ \end{array} \right\}$ $\longrightarrow$ $H^+ +$ $\left\{ \begin{array}{l} H \\ O \\ N \end{array} \right\}$

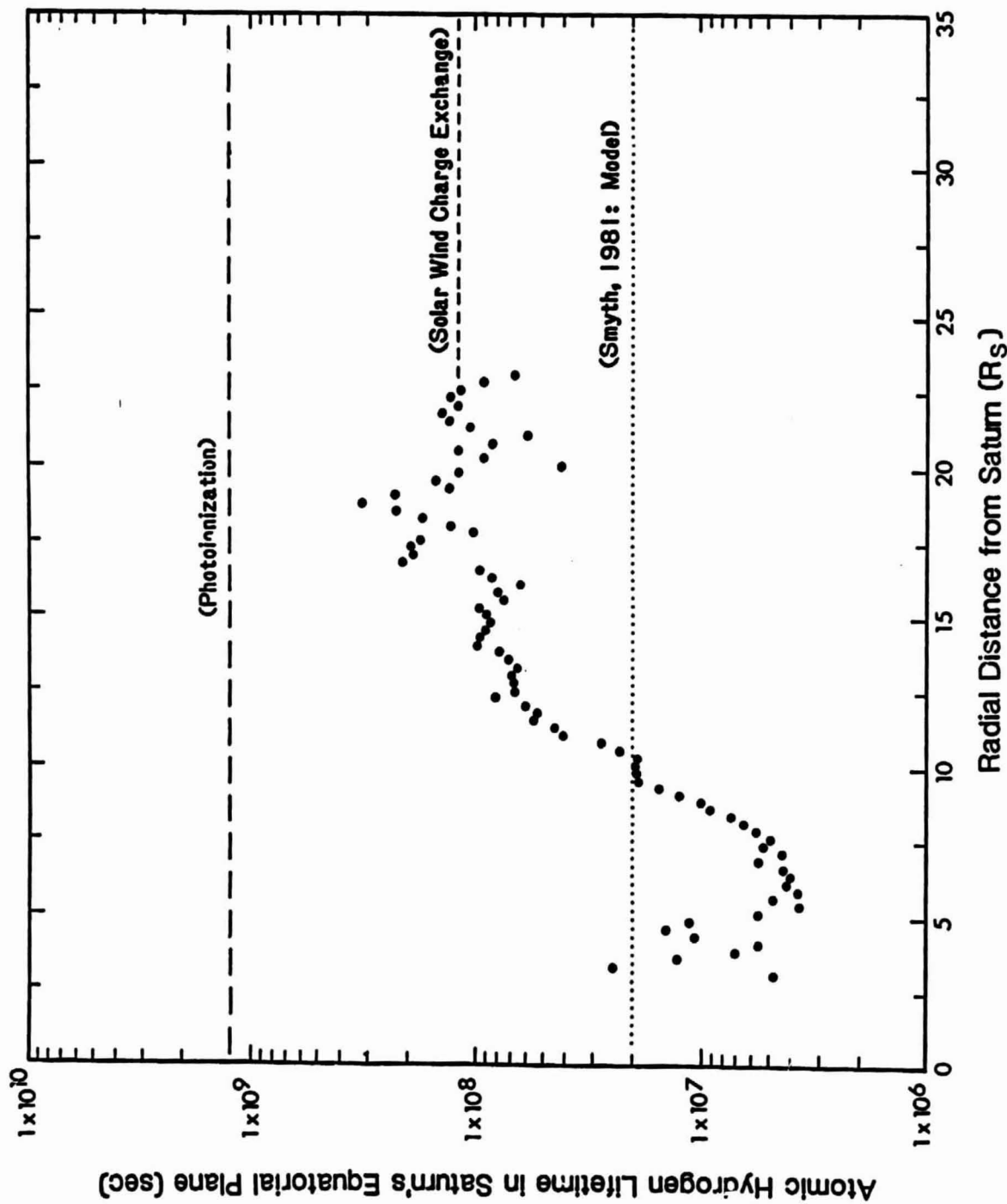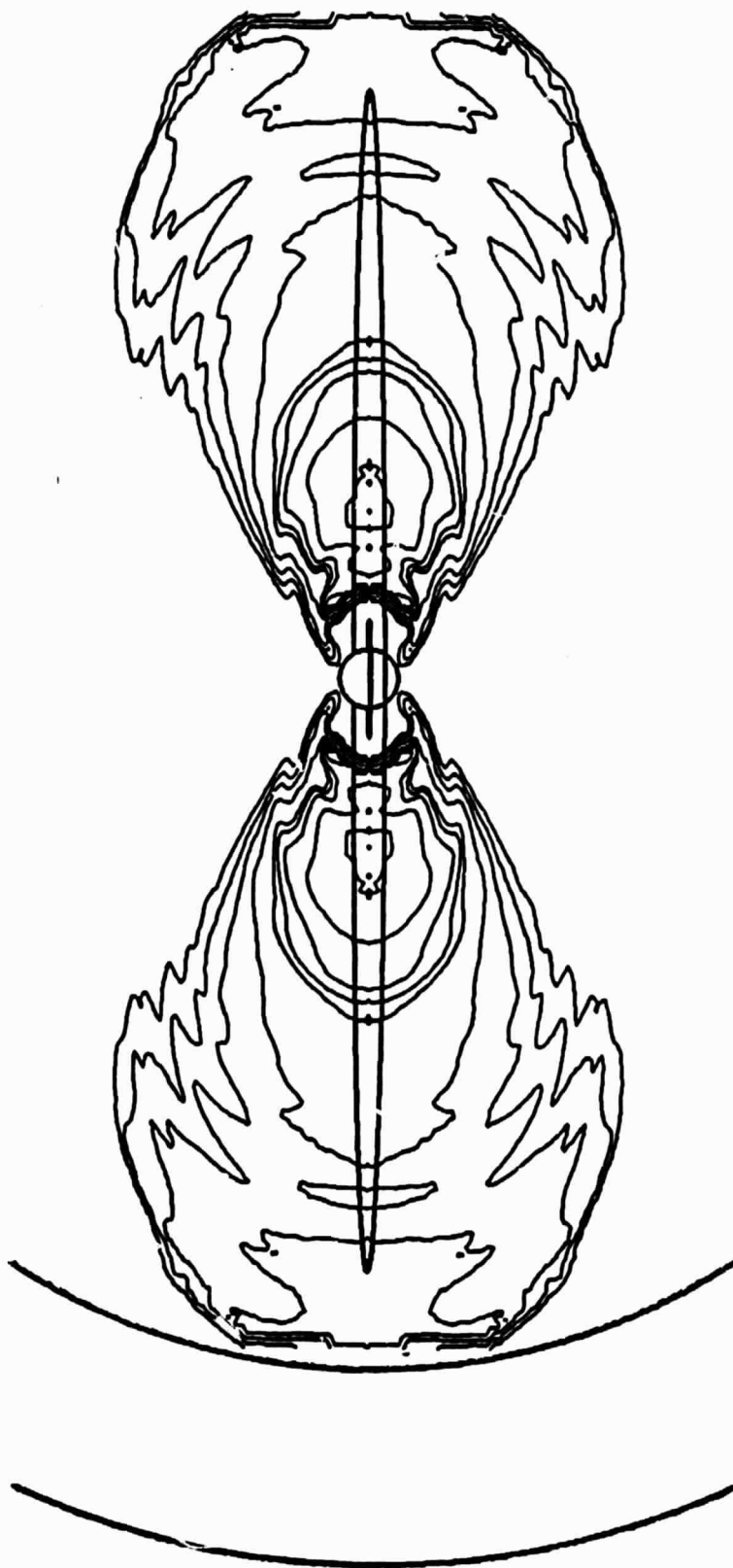3. $\quad$ H $+$ $\quad h\nu$ $\longrightarrow$ $H^+ +$ e

Figure 1. Lifetime of Atomic Hydrogen in Saturn's Magnetosphere.

The lifetime is appropriate for the reactions of Table 1 and the plasma information based upon an analysis of the Voyager PLS data by Sittler (1984).

Magnetopause

Bow Shock

Figure 2

Lifetime of Atomic Hydrogen in Saturn's Magnetosphere

The lifetime is calculated for the three loss processes described in Table 1. The electron and ion (H^+, O^+, N^+) densities and temperatures were obtained privately from a new analysis of Voyager plasma data performed by Sittler (1984). Contour values are, from outside to inside, 1×10^9, 7.5×10^8, 5×10^8, 2.5×10^8, 1×10^8, 7.5×10^7, 5×10^7, 2.5×10^7 and 1×10^7 sec.